Sound Velocity Measurements of Al_2O_3-Enriched Silicate Perovskite and Effect of Aluminum on the Elasticities

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Introduction: Inferences of the chemical compositions of Earth's mantle rests on comparing laboratory-derived equations of state of mantle phases with seismically determined properties of the material *in situ*. Al_2O_3 is known to b present in about 4-5 mole percent for all proposed mantle compositions, such as pyrolite and piclogite. Under the pressure and temperature conditions of the lower mantle, all Al_2O_3 is believed to be incorporated into (Mg,Fe)SiO_3 perovskite, which is generally accepted to be the most dominant phase in Earth's lower mantle[1]. More importantly, a recent study[2] has revealed that silicate perovskite containing 5 mole percent Al_2O_3 yielded different values of the equation of state parameters, with the bulk modulus being significantly lower at lower mantle conditions than aluminum-free perovskite. To further understand the effect of aluminum substitution and to obtain a complete set of elastic data for Al-enriched perovskite (the bulk and shear moduli and their pressure and temperature derivatives), we have carried out elastic wave velocity measurements on a polycrystalline specimen of $MgSiO_3$ perovskite containing 5 mol% Al_2O_3.

Methods and Materials: The polycrystalline Al-perovskite sample used in this study was hot-pressed using USSA-2000 high pressure apparatus at ~25 GPa and 1500 °C. It has 0.952 mm in thickness and about 1.6 mm in diameter after final polishing for acoustic experiment. X-ray diffraction data indicate that the starting sample consists mostly of perovskite with up to 10% of majoritic garnet, estimated based on the relative intensities of the two phases. The high P-T experiment was performed in a DIA-type cubic anvil apparatus (SAM85) installed at the superwiggler Beamline X17B1 at NSLS in Brookhaven National Laboratory. A dual mode Lithium Niobate transducer (10 degree Y-cut, 30 MHz for S wave and 50 MHz for P wave) mounted at the back of the WC anvil enabled us to collect travel time data for both P and S waves in a single experiment. Cubic boron epoxy cube (6.15 mm edge length) was used as pressure medium. The sample was placed in the center of the boron epoxy cube with NaCl and BN as surrounding materials. A glass buffer rod was inserted into the cell assembly between the WC anvil and the sample with gold foils (2 micron thickness) placed at the interface between sample and buffer rod as well as at the buffer rod and WC anvil interface to enhance the mechanical coupling. The sample pressure was determined using Decker pressure scale from the X-ray diffraction data for NaCl and the temperatures were measured by a W-Re thermocouple.

Results: The specimen showed good acoustic quality for bench-top velocity measurements for both compressional (P) and shear (S) waves. The P and S wave travel times as well as pressure, temperature and sample volumes (P-V-Vp-Vs-T) were measured simultaneously along several heating/cooling cycles in the ranges up to 8.6 GPa and 873 Kelvin. From these data, P and S wave velocities are calculated, with the sample length at high pressure and high temperatures determined from the measured sample volumes at the same conditions [$l/l_0=(V/V_0)^{(1/3)}$]. Preliminary data reduction reveals that, after correction for the presence of garnet phase, the ambient bulk and shear moduli of Al-perovskite are respectively 230 and 154 GPa, with the corresponding first pressure derivatives of 5.1 and 2.4. The bulk modulus obtained in this study is similar to the earlier published values by Zhang and Weidner[2], but it is 20 GPa smaller than that of Al-free $MgSiO_3$ perovskite, obtained using the identical experimental technique under similar pressure and temperature conditions[3]. These two new studies thus support the earlier suggestion[2] that Al may have significant effects on the elasticity of mantle perovskite. We are currently analyzing the P-V-Vp-Vs data collected at high temperatures.

Conclusions: The elastic P and S wave travel times have been measured up to 8.6 GPa and 873 K on a $MgSiO_3$ perovskite containing 5 mol% Al_2O_3. The resultant Vp, Vs, K and G at ambient temperature are substantially smaller than those of Al-free $MgSiO_3$ perovskite, obtained from static compression experiments and ultrasonic measurements. That Al may have significant effects on the elasticity of mantle perovskite is thus demonstrated by independent studies using different experimental techniques.

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References: [1] T. Irifune, Nature 370, 131 (1994). [2] J. Zhang and D.J. Weidner, Science, 284, 782 (1999). [3] B. Li, J. Zhang and D.J. Weidner, NSLS Ann. Rep., 2000.